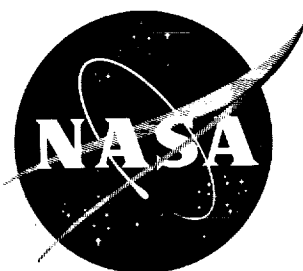


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TECHNICAL NOTE

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PHYSIOLOGICAL SENSORS
FOR USE IN PROJECT MERCURY

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PHYSIOLOGICAL SENSORS FOR USE IN PROJECT MERCURY

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SUMMARY

A development and test program was conducted to determine the most suitable sensors for measuring the various physiological indicators to be used in Project Mercury. These sensors included body core temperature, respiration rate and depth, and electrocardiogram. The selected sensors have proven their reliability in three suborbital flights.

INTRODUCTION

With plans of Project Mercury's orbital flight and its prolonged weightless state during orbit, the necessity for obtaining clinically acceptable physiological data from the astronauts has been widely recognized. In the Mercury orbital flight, there will be little opportunity to give assistance to the astronaut in case of an emergency; therefore, it is important that basic physiological indicators of such items as heart rate, respiration, body temperature, and the electrocardiogram be used. Since weight was of prime concern, all electrical components were miniaturized. Only a limited number of monitoring channels were available. During the planning stage, three channels were allocated for biomedical indicators. The biomedical sensing indicators to be used in the Mercury program are: (a) body core temperature (rectal), (b) respiratory rate and depth, and (c) electrocardiogram (ECG).

These physiological sensing indicators have been used regularly as standard aeromedical procedure for measuring the physical condition of a subject in centrifuge or altitude-chamber studies of short duration. These sensors which employ a "hard line" electrical system have also been used to a limited extent for in-flight testing (ref. 1). The standard sensing-type transducers are satisfactory for a few hours duration, but since the requirements for Project Mercury are for durations up to 24 hours, it became necessary to develop new sensors or to modify existing sensors.

It is the purpose of this paper to present the tests and methods used in selecting the most satisfactory biosensors for use in Project Mercury.

DESIGN REQUIREMENTS

Design development for a satisfactory sensor package was started at McDonnell Aircraft Corporation. In support of the McDonnell development, NASA Manned Spacecraft Center (previously called Space Task Group) developed several designs for each type of sensor and conducted a series of tests to determine the one most suitable for Project Mercury. At the same time, an extensive literature survey was carried out, and a number of visits were made to various laboratories and institutions where new or modified sensors were in use. Although many new types of sensors were being used or tested, none were believed to meet the requirements in Project Mercury.

Because the occupant of a spacecraft must perform flight tasks and because the dynamic loads applied to the vehicle are considerably greater than those applied to standard airplanes, emphasis must be placed on new transducer designs. The specifications which these sensors must meet are compatibility with the spacecraft electrical system and production of reliable data. In addition, these sensors must not interfere with the duties of the pilot, and they must be comfortable for the duration of the mission.

SENSOR-TEST PROGRAMS

In the schedule of Project Mercury there was a series of astronaut-training programs during which biosensors were also tested. The training program included postlanding heat profiles, altitude tests, and centrifuge training tests. Various biosensors were selected for use during these programs to test and compare their reliability. When alternate systems were available, each was tested and the most reliable was chosen.

The postlanding heat-profile tests were made at the U.S. Navy Air Crew Equipment Laboratory (ACEL), where two ECG electrodes, two types of body temperature sensors (a rectal probe and a thermoinsulated disk), and two respiration sensors (a linear potentiometer sensor and a rotary potentiometer sensor) were tested for their reliability and correlation. The altitude tests were made in a manned spacecraft chamber at McDonnell Aircraft Corporation, where only McDonnell developed sensors were investigated.

The centrifuge training tests were made at the U.S. Navy Aviation Medical Acceleration Laboratory (AMAL), where the Mercury-Redstone and Mercury-Atlas acceleration profiles were simulated. A complete biosensor assembly was tested to ascertain its characteristics during acceleration. The test sensors consisted of a rectal probe, three types of respiration sensors, and three types of ECG electrodes.

Since the Mercury program provided for a chimpanzee to precede man in both suborbital and orbital flights, these animals were trained to perform a prescribed psychomotor response in order to duplicate as closely as possible the man-flight task. When possible, the animal would use the same biosensors as the man, but some modifications were necessary because of characteristics peculiar to the species. The modifications were compatible with the telemetry system of the spacecraft and were made only to enhance the ease of working with the animal. The animal would, as far as possible, be used to test the human bioinstrumentation techniques, including telemetry and monitoring.

BODY CORE TEMPERATURE SENSOR

Body temperature has been used for some time as an indicator of physiological stress and the data have been validated; therefore, records of temperature in Project Mercury were desirable. One of the most accurate and reliable methods for obtaining body-temperature reference to a stress situation is the 10-point mean weighted skin temperature. The disadvantage of the mean weighted skin temperature system is that it requires multiwire leads which could impede the movement of the vehicle occupant. It was thought that the most effective temperature indication, with the least number of wires, would be a rectal probe sensor. It was decided that a rectal probe utilizing a thermistor sensing unit would be used.

Probe Configuration and Selection

Most of the rectal probes presently used are inserted 4 to 6 inches and are $\frac{1}{8}$ inch to $\frac{1}{4}$ inch in diameter. These probes produce discomfort for the subject after prolonged use, and certain psychological rejections imposed by instinct and culture also become manifest. Various studies conducted on the effects and reliability of rectal probes (ref. 2) indicate that even when the probe is inserted 4, 5, 6, or 8 inches, in most cases the thermistor tip bends back and lateral so that the tip cannot be considered at a graded depth within the rectum and sigmoid. It was hoped that if physical size (that is, diameter and length were reduced

to a minimum and the insertion length held to 2 to 3 inches, the comfort level would be increased without loss of accuracy.

Several rectal probe configurations were designed and fabricated at the Langley Research Center. The Langley fabricated probes and the McDonnell developed probe, together with a couple of commercially purchased probes (fig. 1) were tested on personnel from the NASA. The probe was left in the subject up to 8 hours, and the subjects reported their objections to each type. The test results indicated that the McDonnell probe had the best comfort index. During the AMAL centrifuge program, only the McDonnell developed rectal probe was used. After the rectal probe was used on three subjects, the amplifier system failed and no more body temperature tests were conducted. Although the probe gave satisfactory recordings of the body temperature, there was some physical discomfort caused by the tendency of the probe to pull because the lead wire was too short. When the wire was lengthened on later models, this discomfort was eliminated. During other test programs, the rectal probe has given satisfactory results. The McDonnell developed probe is 2 inches in length with a thermistor at the tip imbedded in a coating of latex rubber; the first $1\frac{1}{4}$ inches is $\frac{1}{8}$ inch in diameter with the remaining length $\frac{3}{32}$ inch in diameter. Following a right angle bend, the latex rubber coating continues beyond the 2-inch length for another 3 inches. The probe is bent 2 inches from the tip for easy reference so that the proper insertion length is maintained.

During the Project Mercury testing program, it was learned that North American Aviation, Inc. was using a new type of rectal probe in the X-15 program. This probe was similar to the McDonnell probe except that it had a holding bulb placed on the probe so that the bulb rests on the inner confines of the sphincter, so that the holding bulb would give a point of rest for the sphincter and would thereby increase the comfort of the probe. The remarks of the test subjects concerning a test sample indicated that the holding bulb made insignificant difference to comfort. Therefore, the holding bulb was removed from the probe for Project Mercury.

A thermoinsulated disk (ref. 3) that imprisons a heat sensing thermistor (fig. 2) has been developed by Boeing Airplane Company. This sensor is a glass "thermocup" about $2\frac{1}{2}$ inches in diameter; in the center, there is a sponge-rubber mound which supports the thermistor. This sensor is attached on the surface of the body on the axilla line and is held in place by a web belt. If this thermoinsulated disk proves reliable and gives temperature correlation with reasonable reproducibility, this sensor could replace the rectal probe. During the Mercury reentry heat-profile test at ACEL, the thermoinsulated disk was tested on three

different individuals. The temperature records for two subjects using this disk taken simultaneously with those for the rectal probe showed that the insulated disk had a long time lag at stress threshold (figs. 3 and 4). Although the records do show correlation of the data obtained with the disk and the rectal probe to the point of stress threshold, there were not a sufficient number of tests to establish reliability of the disk as an indicator of the physiological heat stress. It was decided not to use this particular sensor in Project Mercury.

It is concluded that there is a need for a survey and an experimental control study to determine the reliability and degree of variation of various external regional temperature devices. If it can be demonstrated that the body-surface temperature-measuring sensor is accurate and consistent, then it would ultimately be possible to eliminate the conventional rectal probe and substitute a surface-type sensor in later projects.

Animal Sensor

During the animal training programs, the animal would extrude the selected rectal probe. When a standard Yellowsprings animal probe no. 401 was used in place of this probe, the results were satisfactory.

RESPIRATION RATE AND DEPTH

The respiratory cycle of an individual under stress conditions may increase or decrease, which makes the use of a respiratory sensor of interest. To obtain quantitative respiration analysis, the Haldane method of gas collection is by far the most accurate. Since this system requires gas-collecting apparatus and elaborate postflight instrumentation for analyzing the expired air, it was necessary to use a simpler method of monitoring respiration rate in Project Mercury.

Respiration Rate and Depth Sensor

The simplest type of sensor would be one that uses the pneumographic technique - a linear or rotary potentiometer.

Three basic types of respiratory sensors were tested:

- (1) Linear potentiometer
- (2) Rotary potentiometer
- (3) Thermistor sensing

The linear and rotary potentiometer sensors use a web belt worn around the chest. A potentiometer is attached to an elastic center section woven into a cotton web belt. This belt is worn around the chest at approximately the xiphoid process or at the nipple line. These pneumographic sensors are unreliable because they do not prove that air is moving into and out of the respiratory passages. The subject could create a false response by tensing his muscles and could cause registrations by chest contractions against a closed glottis. The physical resistance of the linear potentiometer (first developed by McDonnell) increased with extension of the potentiometer, so that the subject's breathing was impeded and discomfort occurred in a very short time. This physical resistance to chest expansion is not present to the same degree in the rotary-type sensor (developed by Boeing Airplane Company), hence, the comfort is greater for longer periods.

A more direct method would be to use a thermistor to record the air movement. This old technique was adapted to Project Mercury by mounting the thermistor heated to 200° F on the lip microphone. This sensor also has the merit of eliminating chest straps and of being located where it does not interfere with the movements of the astronaut.

Sensor Testing

Three sensors were tested in the manned program at ACEL, AMAL, McDonnell, and the NASA Manned Spacecraft Center. At ACEL during the Project Mercury heat-profile tests, the McDonnell linear- and Boeing rotary-potentiometer belts (fig. 5) were tested. Each sensor was worn twice and for a period from 8 to 14 hours by two different subjects. The linear potentiometer belt was rejected because few satisfactory records were obtained and because the belt caused such a great resistance to breathing that it became uncomfortable in a very short time. The Boeing rotary potentiometer functioned satisfactorily for the first 2 to 3 hours, after which the web belt holding the sensor became soaked from the subject's sweat to the point that the webbing stretched and the sensor became too loose to give any deflection. No discomfort from this sensor was experienced by the subjects. It was believed that, if the webbing were changed to another material (Velcro closure), the problem of stretching would be eliminated. The rotary potentiometer was found easier to adjust to the individual, and the reflected respiratory cycle had more accuracy than did the linear potentiometer. The rubber center portion of the linear potentiometer was reworked at McDonnell, tested at McDonnell and the NASA Manned Spacecraft Center, and found to have

decreased the physical resistance in comparison with the original, but the resistance still remained greater than that of the rotary potentiometer.

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The improved McDonnell linear and the Boeing rotary potentiometer belts were tested again on the centrifuge at AMAL during the first centrifuge training program. Both belts were placed on the subjects as directed by the manufacturers, the Boeing rotary belt around the chest at the nipple line and the McDonnell linear belt around the chest at the base of the sternum. Two biosensor assemblies were used on the centrifuge at AMAL. One bioassembly had the linear potentiometer sensor, and the second bioassembly contained the rotary potentiometer. Five tests were made using the linear potentiometer. Three tests failed to give effective respiration data with the belt at the base of the sternum. Two tests were conducted with the belt raised to the nipple line of the chest. At this location, there was some success but not to the point of acceptability. At both locations the adjustment of the belt was critical. For the belt to function, it must fit snugly, but if it is too tight, the belt causes undue pressure on the subject's chest because of insufficient travel of the piston of the linear potentiometer.

The rotary belt was used on six subjects and was found to be superior to the linear belt. If the belt webbing were changed to a different material (Velcro closure), a greater range in adjustment would be obtained.

For standard centrifuge testing, AMAL uses a thermistor respiration sensor which is mounted close to the mouth and nostrils. Three centrifuge runs were made by using the thermistor against the rotary belt for correlation. Figure 6 shows a comparison of the sensors tested. The thermistor test results were superior to the rotary potentiometer; therefore, NASA Manned Spacecraft Center requested McDonnell to develop a thermistor sensor to be attached to the astronaut's lip microphone.

A number of designs were investigated, from a thermistor bead enclosed in a separate container to the final design of a funnel-shaped container inserted over the lip microphone (fig. 7). The main problem was to be able to have the thermistor properly placed to channel all expirations across the thermistor. The first sensor used two thermistors, one for the mouth and one for the nostrils. These thermistors were at first placed in series but were later changed to be placed in parallel, as the series circuit caused an additive effect and over-drove the amplifier system. Finally a design in which a flat funnel-shaped housing containing one thermistor was inserted directly over the microphone was evolved. The funnel portion channels expiration from the nostrils while the opening at the bottom close to the microphone would channel expiration from the mouth.

This thermistor enclosed in a funnel housing was given to McDonnell for fabrication and testing. It was discovered at McDonnell that the thermistor did not satisfactorily meet some of the conditions imposed by the spacecraft environment. When used in a bridge circuit at low current, the output was too low without amplification. Because the thermistor responded to ambient temperature, the thermistor was heated to a temperature above the surroundings. The final unit was supplied a 6-volt excitation current that heated the bead to 210° F. During the ACEL and second AMAL training program, this sensor was used with very good results. The sensing is done by dissipated heat across the thermistor due to the flow of air from the nostrils and mouth.

This technique gives only an indication of air movement and does not give quantitative information about the volume of gas inhaled, for if the pilot moves his head within the helmet away from the microphone, a lowering of the respiratory amplitude, which is not related to the volume of gas exchanged, is produced. The problem of a quantitative respiration rate and depth sensor is still under investigation. Figure 8 shows a section of the respiration recorded during the MR-3 flight (ref. 1).

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Animal Respiration Sensor

Design problems arose when the potentiometer planned for the man was adapted for the animal. Several new types of potentiometers were tested: a carbon microphone button attached to the rib cage; and a conductive rubber link in an elastic combination chest and abdominal harness, because it was found that when the chest area was restrained, the animal would breathe through the abdomen and vice versa. Manufacturing quality control of the conductive rubber ribbon was inadequate to provide uniform material, which made selection of the straps difficult, and the system was abandoned.

Several harnesses were tested at Holloman Air Force Base, by using the old technique of a rubber tube filled with copper sulfate. This harness (fig. 9) showed promise and NASA Manned Spacecraft Center requested McDonnell to continue further development. A prototype sensor was tested during the chimpanzee altitude chamber test conducted at Cape Canaveral, Florida. During the test, the output went off scale when the couch passed 25,000 feet and returned when the altitude lowered. It was concluded that this was caused by abdominal gas expansion at reduced external pressure. This condition was corrected by designing an alternating-current coupled amplifier to maintain a constant reference point at 1.5 volts. On subsequent tests, the transducer has functioned satisfactorily.

ELECTROCARDIOGRAM SENSOR

The monitoring of electrocardiograms (ECG) from moving subjects has gained emphasis in the last few years. More and more the ECG is being recognized as a tool for measuring the effects of physiological stress upon a subject.

Many types of ECG electrodes are being used today for recording the status of the working subject, but they are not compatible with the Mercury amplifier system. Most of these systems use standard electrode paste or an electrolyte which is hypertonic. The hypertonic nature of the electrode paste presents no difficulty until after 24 hours of wearing, when it then causes considerable irritation to the attached area. As the paste dries out it loses conductivity, so that electrode-to-skin resistance increased and the electrode is rendered less effective.

The Mercury ECG preamplifiers have an input impedance of 25,000 ohms, whereas the human skin has an external resistance of 75,000 to 100,000 ohms. There is also the problem of baseline shift when ECG's are obtained from subjects engaged in muscular movement (ref. 4). The requirements for an electrode to meet the specifications for Project Mercury should be: good electrical contact between the electrode and the subject's skin, easy application, no interference with the subject, and a resistance compatibility with the amplifier system. The electrolyte should be nonirritating to the skin, slow-drying, with high viscosity, and should be able to maintain resistance stability over the required mission.

Electrolyte

The first problem was to find an electrolyte that would maintain a moist area and be nonirritating for the duration of the mission. Tests were made on a total of 10 subjects using 36 different combinations of attachments and electrolyte compounds. Two 1-inch diameter watch-cover glasses were used. These covers were filled with various electrolytes and placed on the subject's skin. One glass was attached to the back on the trapezius muscle; the other was attached to the chest lateral to the sternum. It was apparent from these tests that a method for sealing off the electrolyte was needed to keep the jelly from drying out.

Some of the various types of electrode attachments are as follows: adhesive tape; Duke Laboratory elastoplast adhesive-tape collodion spray; adhesive tape with collodion spray, gauze with collodion; gauze with collodion and adhesive tape. The following are some of the various types of electrolytes used: Redux standard ECG jelly; surgical

jelly (plain and mixed with silver powder, or calcium chloride, or with sodium chloride); bentonite EEG paste; and modified bentonite. In addition, steel wool and bronze wool, plain and soaked in Redux or surgical jelly, or bentonite were tried. Of the electrolytes tested, only three showed promise; the rest either had too high a resistance (over 70,000 ohms) or when left on for the required period became extremely irritating or had a high resistance increase. The three electrolytes showing the greatest promise for use in Project Mercury were: bronze wool soaked in Redux, McDonnell modified bentonite, and NASA modified bentonite.

The bronze wool soaked in Redux was subsequently disqualified because of some irritation to the subject after a 24-hour period and because it was inconvenient to use. The modified bentonite compound used by McDonnell (10 grams of bentonite, 10 cubic centimeters of water, 4 grams of calcium chloride) caused some redness after 24 hours, but the irritation was not considered serious; however, after 38 hours, this electrolyte caused considerable irritation (fig. 10). It was concluded that the best electrolyte was the NASA modified bentonite compound (15 grams of bentonite, 10 cubic centimeters of water, 3.0 grams of calcium chloride), as there was no irritation present after 48 hours of attachment.

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Electrode Configuration

One of the most efficient types of ECG electrodes is the platinum suture. This is a fine wire that is stitched under the skin. This electrode has good skin contact and very low resistance because it pierces the epidermis with its high resistance and gains contact with the more conductive soft tissue under the skin. (An example of this type electrode is shown in fig. 11.) However, there are obvious objections to using this type of electrode since it is to the subject's advantage not to puncture the skin. Therefore an electrode development program was conducted at McDonnell and a similar in-house program was carried out by the NASA Manned Spacecraft Center. There were several types of electrodes designed and fabricated at Langley Research Center. The types studied included:

- (1) A $\frac{1}{2}$ -inch diameter machined stainless-steel cup.
- (2) A 1-inch stamped stainless-steel cup. The stamped cup is a NASA Manned Spacecraft Center development design.
- (3) A 2-inch stamped stainless-steel cup.
- (4) Gulton Industry stainless-steel wire mesh. This is the standard commercial type $\frac{3}{8}$ -inch wire mesh.

(5) McDonnell Aircraft $\frac{1}{2}$ -inch stainless-steel wire mesh. This is the same as the Gulton Industry except that the diameter of the mesh has been increased from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch.

(6) Fluid electrode. The fluid electrode is an evolution from the stamped stainless-steel cup designed at NASA. The prototype of this electrode was made at ACEL by Mr. Sam Greco. The fluid electrode used (fig. 12) is a "cleaned up" design made by the Langley Research Center. These electrodes were tested on several subjects for a minimum of 24 hours and a maximum of 72 hours. The subjects were allowed to continue with their daily activity and were instructed to remove the electrodes if they became irritating. Immediately after attachment, a skin-to-electrode resistance was taken on a Simpson volt-ohm-milliammeter Model 260 and an ECG recording was made on a Sanborn Model 100 Viso-Cardiette. Every 12 hours resistance and ECG records were repeated until removal of the electrodes. Just before removal, final resistance and ECG records were obtained.

Of the electrodes tested, three showed promise for use in Project Mercury. These electrodes are: the 1-inch stamped stainless-steel cup, the $\frac{1}{2}$ -inch stainless-steel wire mesh, and the fluid electrode.

Electrode Evaluation

Since the first group of tests showed these three electrodes had possibilities for use in Project Mercury, an additional test program was conducted using only the three electrodes. The same procedure was used for this test group that had been used for the original electrodes. Table I shows the results of tests of the $\frac{1}{2}$ -inch mesh electrode and the fluid electrode. The table indicates that the fluid electrode is superior, since the finishing resistance of this electrode is lower. It was also evident that the electrode had less movement in relation to the skin when the subject did a series of exercises.

Figure 13 is a presentation of sample records of each ECG electrode tested. Note the 60-cycle pickup and baseline shift in the final recordings. This is due to drying of the electrolyte or loosening of the electrode, which causes external electrical interference to be picked up by the electrode. Figure 14 presents ECG results taken through the Mercury amplifier system at McDonnell using the NASA fluid electrode and McDonnell $\frac{1}{2}$ -inch wire mesh electrode. Note that there is less baseline shift in the fluid electrode, perhaps because of the firm attachment of this electrode.

Postlanding Heat-Profile Test

The postlanding heat-profile tests conducted at ACEL afforded an opportunity to correlate the fluid electrode and the McDonnell wire mesh electrode during extreme temperature conditions. After about 6 hours either the McDonnell wire mesh electrode stopped producing an ECG signal or there was interference to the point that the records were not readable. The fluid electrode produced readable ECG throughout the entire test.

During the AMAL centrifuge program, two different biosensor assemblies were used. Each biosensor assembly contained two different sets of ECG electrodes; one contained McDonnell $\frac{1}{2}$ -inch wire mesh and the fluid electrode, while the other set had McDonnell $\frac{1}{2}$ -inch wire mesh, and $\frac{3}{4}$ -inch wire mesh sandwiched between Armstrong vinyl cork (ref. 5). There were six different application techniques used during the program.

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The techniques of application were as follows:

(a) McDonnell $\frac{1}{2}$ -inch wire mesh electrodes; two electrodes placed on the shoulders lateral to the shoulder blades, and one electrode on the thigh, the electrodes were attached with 2-inch square Duke Laboratory coverlets.

(b) McDonnell $\frac{1}{2}$ -inch wire mesh electrodes placed as described in paragraph (a) but attached with Armstrong vinyl cork.

(c) McDonnell $\frac{1}{2}$ -inch wire mesh electrode, one placed on each side at midheart level on the axilla line and third electrode above and medial to the left nipple and attached with 2-inch square Duke Laboratory coverlets.

(d) McDonnell $\frac{1}{2}$ -inch wire mesh electrodes placed as stated in paragraph (c) but attached with Armstrong vinyl cork.

(e) Fluid electrode placed as described in item (c), but attached with Duke Laboratory elastoplast adhesive mass.

(f) $\frac{3}{4}$ -inch wire mesh sandwiched as described in item (c), and attached as described in item (d).

During static test, all electrodes, placements, and attachments functioned as expected, but when the centrifuge turned slowly, the

$\frac{1}{2}$ -inch mesh attached with a coverlet to the shoulder blades did not give a readable ECG record. The other locations and attachments gave fair records up to the 3g level; after this point, the electrodes developed too much hash to distinguish the QRS complex and T-wave. At high g level (9g to 11g) the fluid electrode was the best. This electrode gave distinguishable QRS complex and T-wave through the 11g level. The $\frac{3}{4}$ -inch mesh electrode imbedded in Armstrong vinyl cork has as good results at the 10g level as the fluid electrode. Since this electrode requires Armstrong cork, which has to be replaced after each use, it was decided that the fluid electrode would be used in Project Mercury. Figure 15 is a representation of the various electrodes and attachments taken at static condition and during 4g on the centrifuge.

The Project Mercury ECG amplifier system was originally designed for three electrodes (the left side being common for the two-lead system). If either the right side or upper chest electrode failed, one system would be transmitting, but if the left electrode came loose, both leads would be lost. To eliminate this condition and give better redundancy to the system, the three-electrode system was changed to a four-electrode system. The new placement of the electrodes (fig. 16) was established after consultation with Dr. James A. Roman and Dr. Lawrence E. Lamb of the U.S. Air Force School of Aviation Medicine, and Captain Ashton Graybiel of the U.S. Naval School of Aviation Medicine. A modified clinical lead (designated lead 1) (see fig. 16) or axillary lead was established on the right and left axilla line. The left electrode was placed at the base of the rib cage and the right electrode was placed on the rib cage at the third intercostal space. Lead 2 or sternum lead is at right angles to lead 1 with one electrode on the manubrium and the other on the xiphoid process. These locations were tested on the centrifuge and found to be flight acceptable. Figure 17 is a section of the ECG record taken during the MR-3 flight (ref. 1).

Animal

The texture of the skin of the chimpanzee differs from man and attachment difficulties were experienced at first. Because the suture electrode gives excellent results for prolonged periods, in the animal MR-2 flight wire-suture electrodes (fig. 18) were looped under the skin and tied to a silver-plated button snap. On this flight, however, the thigh electrode was of the fluid type just discussed and upon removal was found to be still in firm contact with the skin.

BLOOD PRESSURE

During the planning period, blood-pressure monitoring was discussed and was considered desirable as a physiological indicator. However, no attempt was made to introduce this system mainly because the state of the art was not sufficiently advanced to consider in-flight use and because of other Mercury systems limitations. In the past few years the state of blood-pressure monitoring has improved, and two systems have been chosen for future trial in orbital flight; one system will be used in manned flight, one in the animal flights.

The animal system involves the gradual infusion through intravascular catheters of anticoagulant to prevent clotting and the direct recording from the catheters onto a compact self-powered multichannel oscillograph.¹

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Recent developments by the AiResearch Manufacturing Division of the Garrett Corporation have improved the technique of blood-pressure recording. In their system, a unidirectional microphone employing a 35-cycle filtering circuit is inserted between an inflatable cuff and the subject's arm. The inflatable cuff is incorporated into the pressure suit, and attached to the cuff is a pressure cylinder which cycles every 140 seconds. The pressure in the cuff ranges between 250 and 40 mm Hg. This system has been tested on the centrifuge at Johnsville and has been found satisfactory. The equipment will be installed in the orbiting Mercury spacecraft. The system will be operational whenever desired by the astronaut and at fixed intervals. One of the ECG channels will be used intermittently to record systolic and diastolic pressure.

BIOSENSOR CONNECTORS

The biosensor connector originally used was a rectangular board with 16 terminal snaps (fig. 19). The suit connector was on the left trunk 1-inch to the left of the oxygen inlet port. The position of the suit connector and the construction of this snap board made it difficult to fasten and to make sure all snaps were engaged. After repeated use, the snaps had a tendency to spread and became loose so that it was impossible to have a good electrical connection.

During the centrifuge test at AMAL prior to the start of a run, several test trials were made on the suit biosensor connector.

¹Subsequent to the writing of this report, the animal system was used during the MA-5 flight on Nov. 29, 1961, and excellent results were obtained.

These tests consisted of having someone put pressure on the whole connector, the ends and the sides, and corners, which, in every instance, would cause considerable interference in the ECG recordings.

A new type of contact was developed (fig. 19) by Bendix Aviation Corporation. The location of this new connector was changed to the outer side of the leg approximately midway between the knee and hip. Since this connector has a positive connection, the new location makes it easier to establish the electrical connection from the biosensors to the outside of the suit.

BIOSENSOR ASSEMBLY

From the results of the various test programs, it was decided that the biosensor assembly would include the following sensors:

(a) Rectal probe, tested at AMAL, with increased lead wire length to relieve the pulling of the sensor.

(b) A thermistor respiratory sensor placed on the lip microphone to record both the mouth and nostril expirations.

(c) Fluid electrode, with a fourth electrode added.

The final biosensor assembly is shown in figure 20.

CONCLUDING REMARKS

The development of the biosensors to be used in monitoring the physical status of the astronaut in orbital flight has been reviewed and evaluation has been made of the sensors selected for use in recording body temperature, respiration rate and depth, and electrocardiogram.

Three flights to date have used the sensors discussed in this paper: MR-2, a chimpanzee suborbital flight, and MR-3 and MR-4 manned suborbital flights. The respiratory sensor did not perform during these flights as satisfactorily as was expected. Several types of respiratory rate sensors are still under investigation.

Manned Spacecraft Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., January 24, 1962.

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TABLE I.- RESISTANCE COMPARISON OF TWO

ECG ELECTRODES 24 HOURS ON SUBJECT

[K = 1,000 ohms; resistance taken on Simpson volt-ohm-milliammeter Model 260]

Subject	Run	$\frac{1}{2}$ -in.-mesh electrode, electrolyte, silver powder			Fluid electrode, electrolyte, 40 percent CaCl bentonite		
		Start	12 hour	24 hour	Start	12 hour	24 hour
A	1	75K	—	150K	1.5K	1.6K	2.5K
A	2	110K	—	800K	3.5K	4.3K	6.5K
B	2	80K	140K	172K	—	—	—
C	2	100K	290K	450K	3.1K	3.1K	2.5K
D	2	50K	72K	250K	—	—	—
E	1	—	—	—	2.5K	2.8K	3.3K
F	1	—	—	—	2.4K	—	4.6K
G	1	—	—	—	2.5K	2.7K	3.0K
Mean	—	83K	167K	364K	2.6K	2.9K	3.7K
Increase	—	—	100%	338%	—	11.5%	42.3%

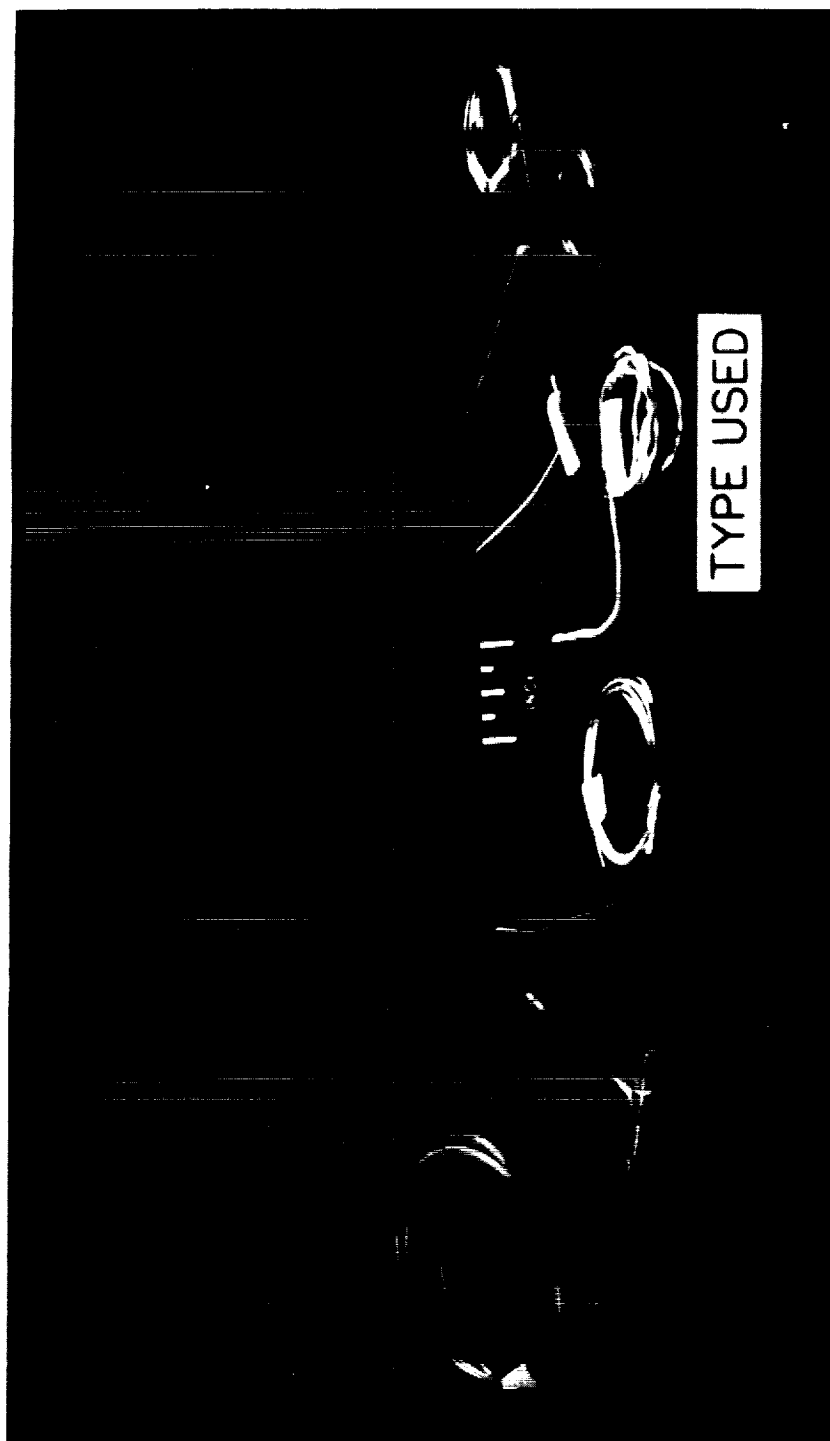


Figure 1.- Various rectal probes tested.

S-61-2426



Figure 2.- Photograph of two body temperature sensors. B-60-145.1

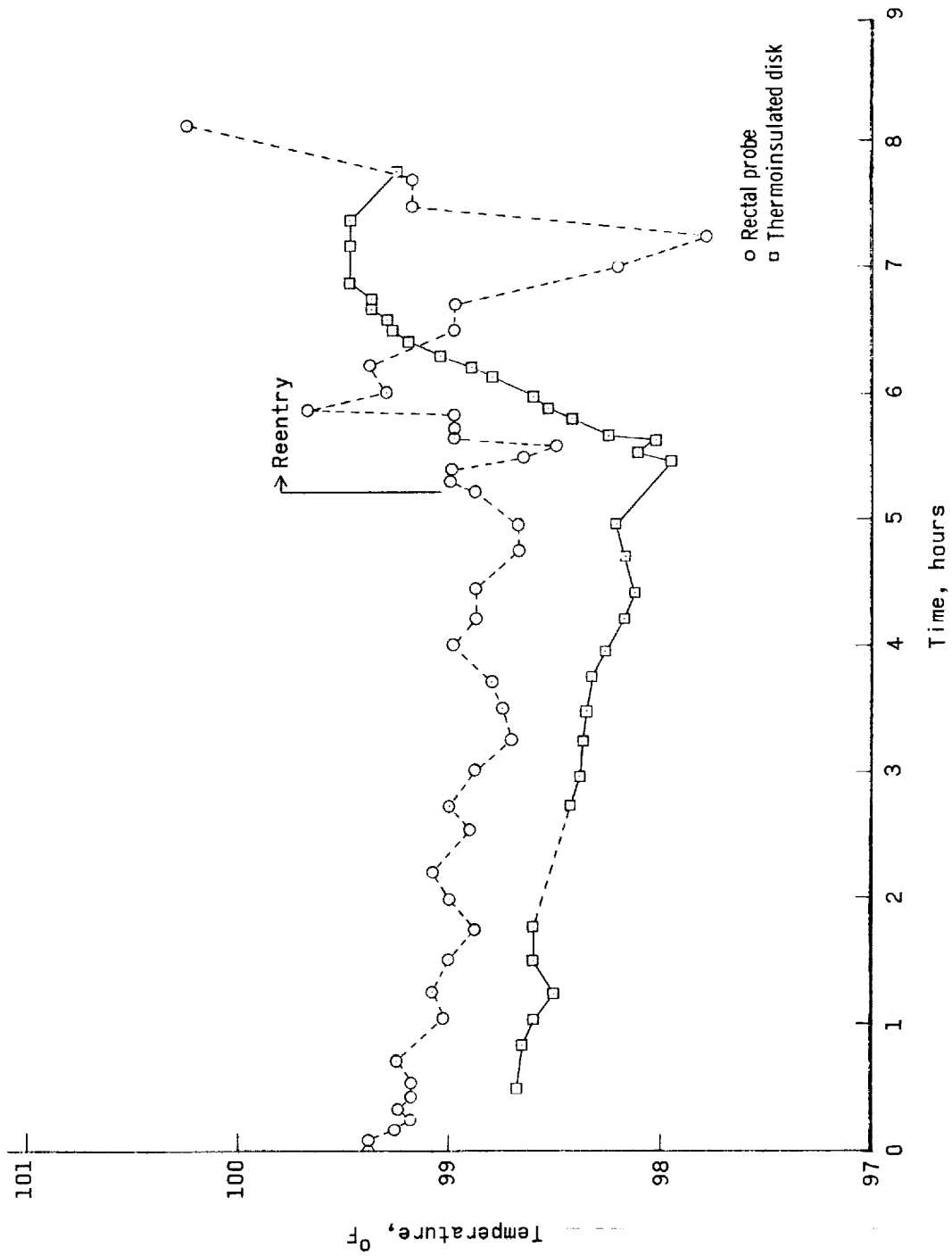


Figure 3.- Comparison of body temperature from rectal probe and thermoinsulated disk - for subject 1.

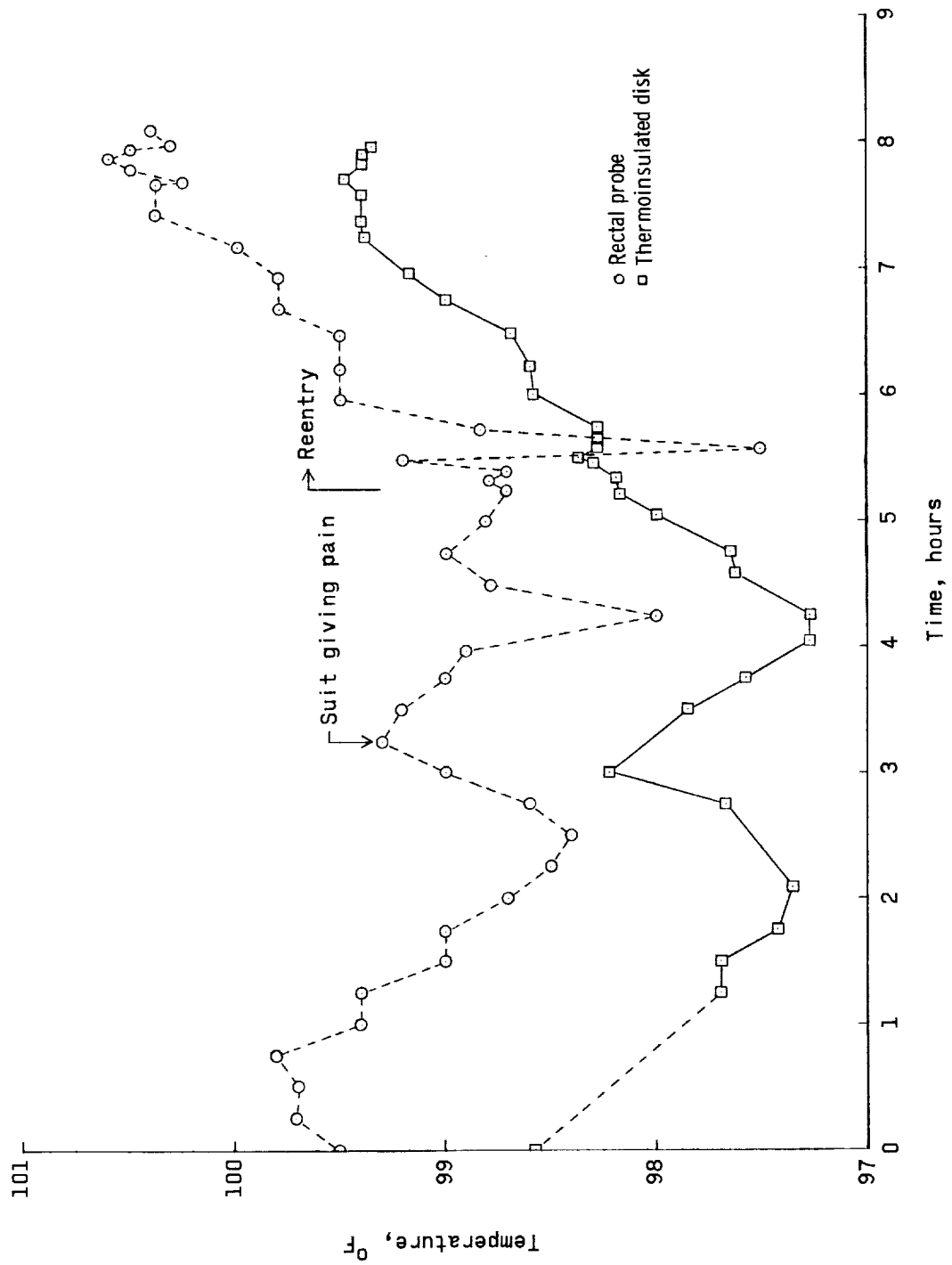


Figure 4.- Comparison of body temperature from rectal probe and thermoinsulated disk - for subject 2.

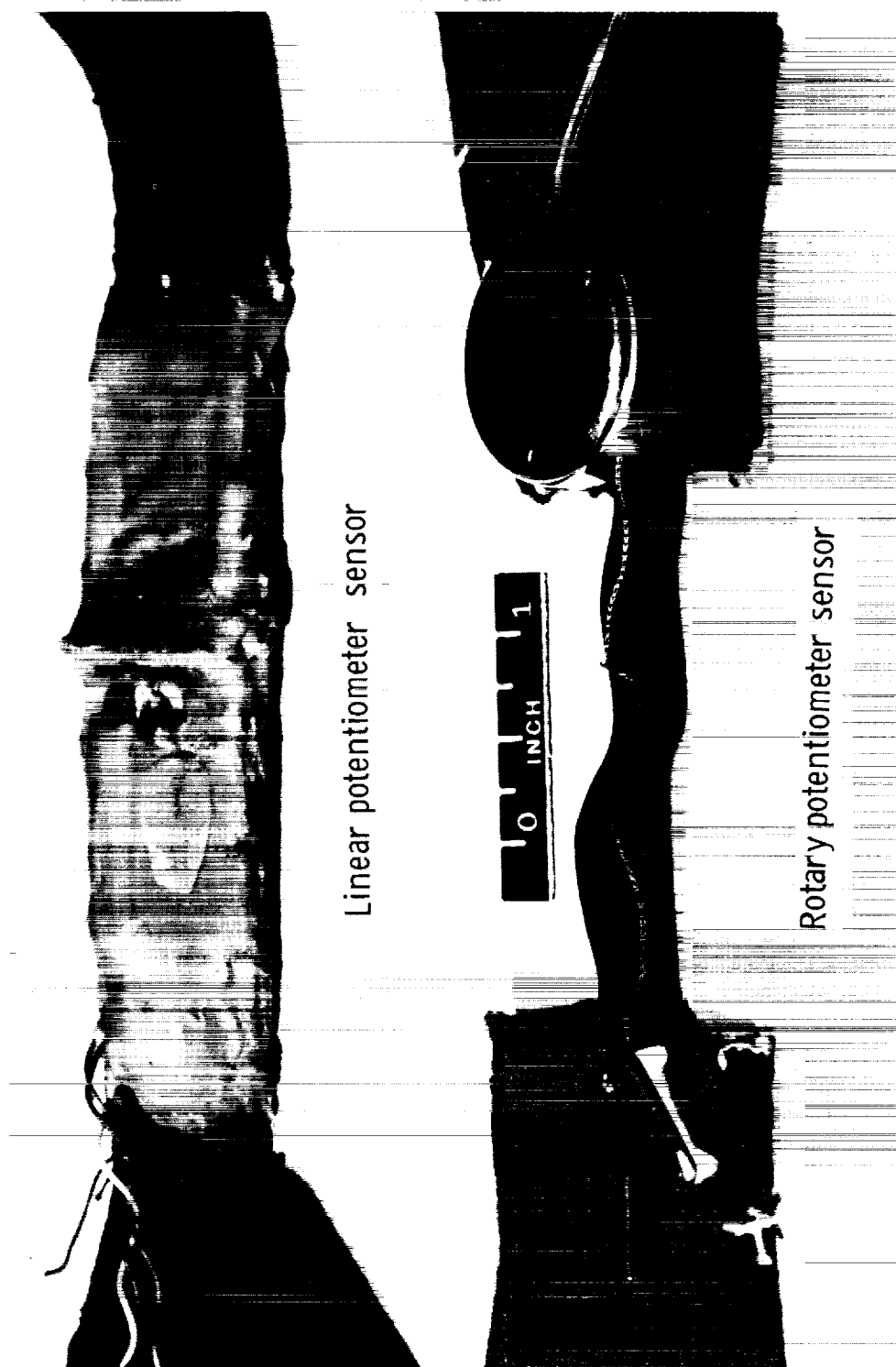
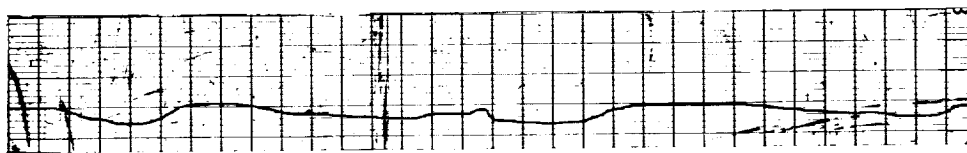
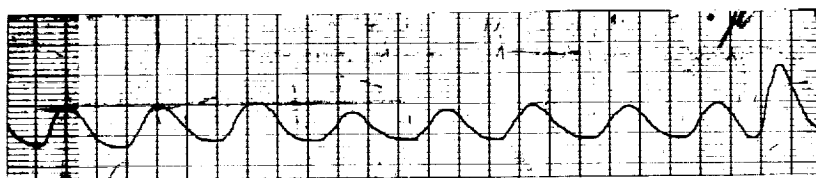


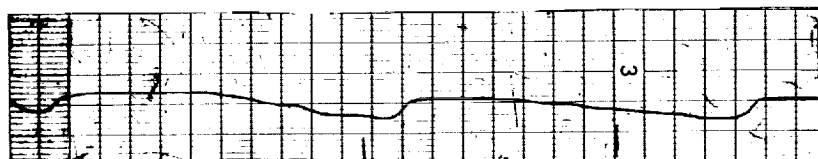
Figure 5.- Photograph of two respiratory rate and depth sensors. B-60-143.1



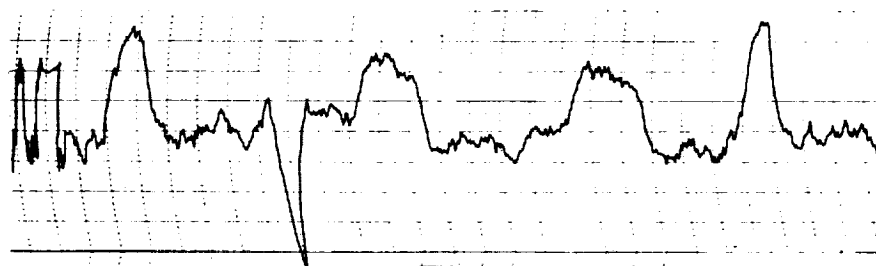
Linear potentiometer belt placed around chest at base of sternum.



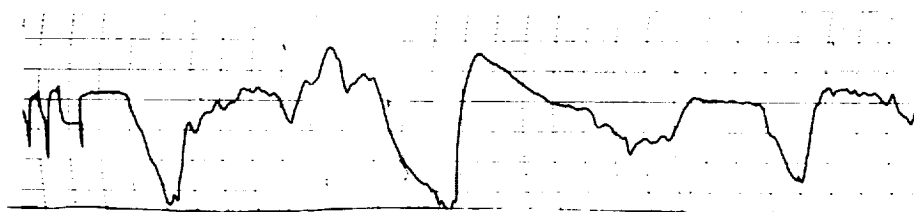
Rotary potentiometer belt placed around chest at xiphoid process.



Linear potentiometer belt placed around chest at xiphoid process.



Chest belt using strain gage.



Thermistor mounted on microphone.

Figure 6.- Respiration recording of various sensors tested.

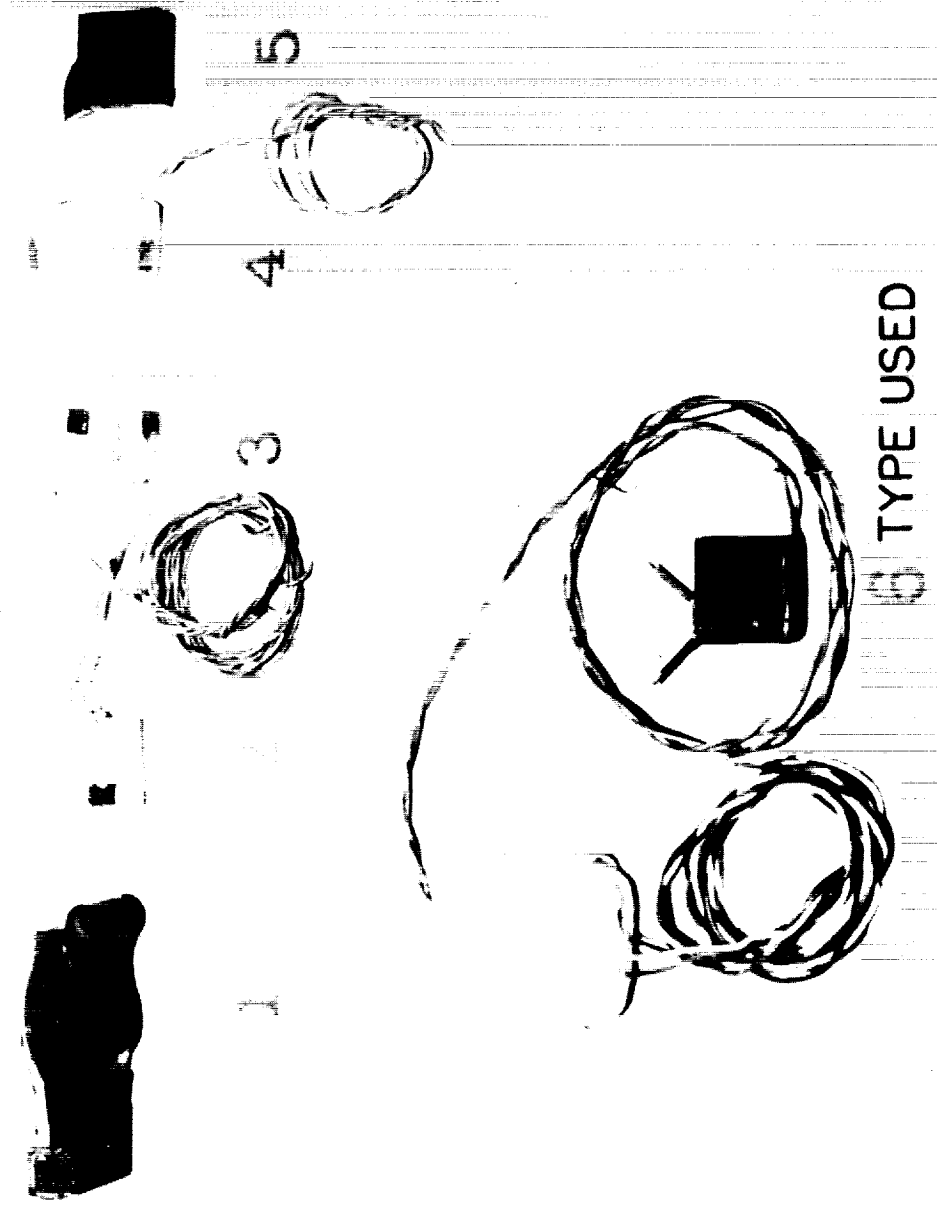


Figure 7.- Respiration rate and depth sensors. S-61-2425

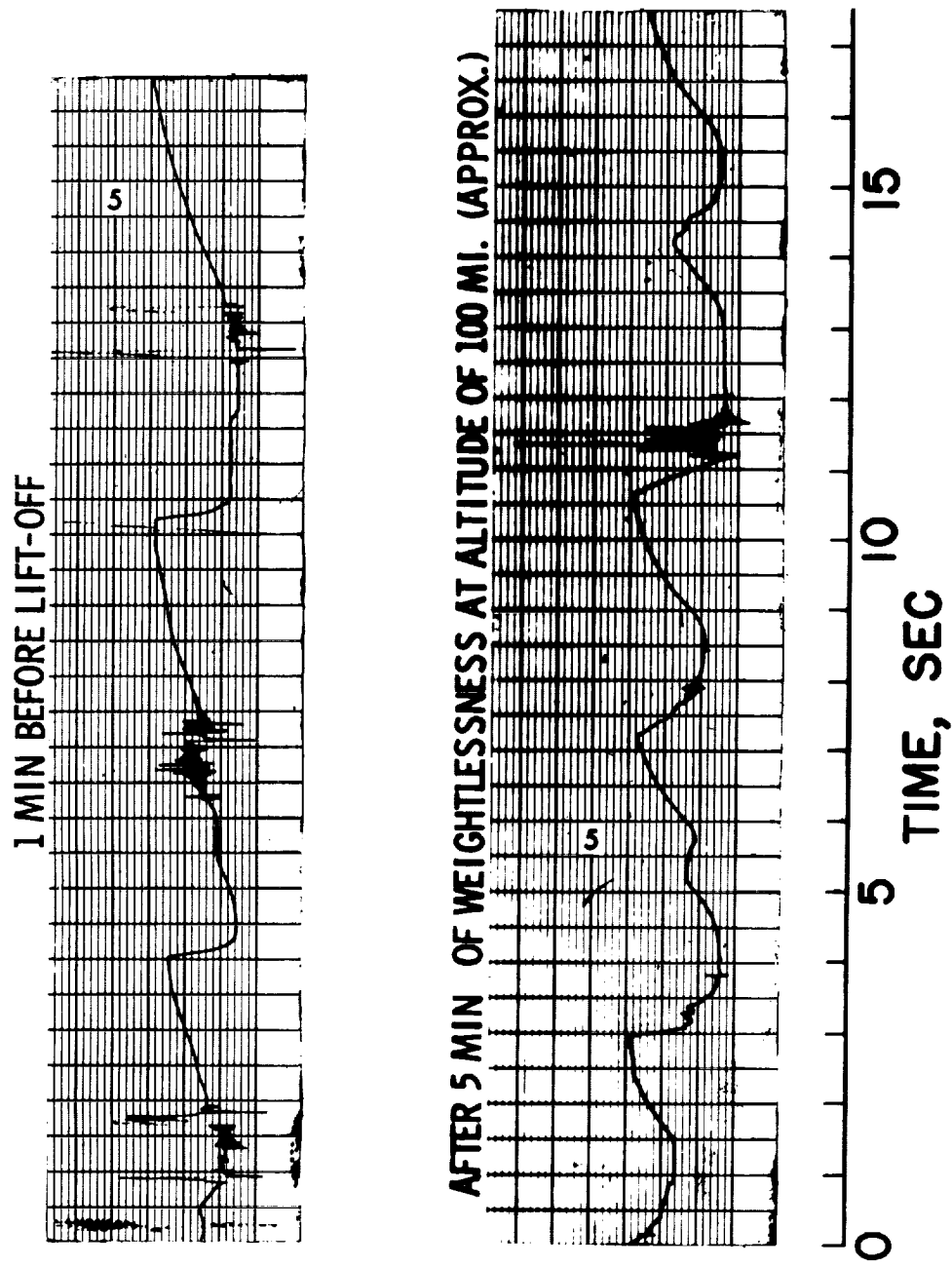


Figure 8.- Respiration record from MR-3. S-61-2424



Figure 9.- Primate respiration rate and depth harness. S-61-2423



Figure 11.- Platinum-electrode suture.

S-62-1

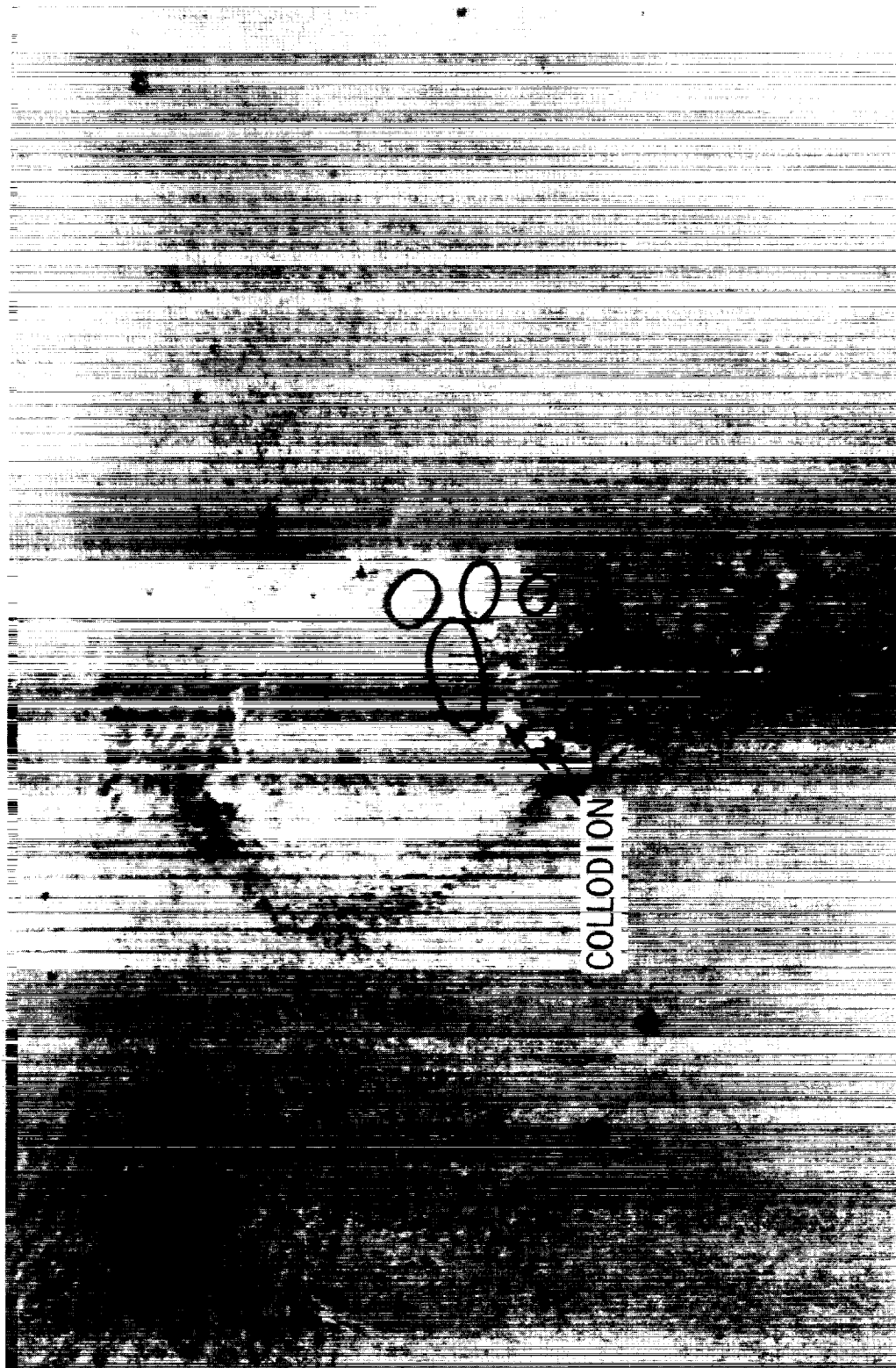
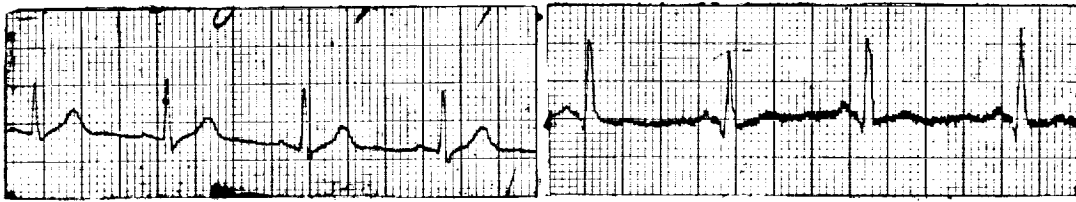


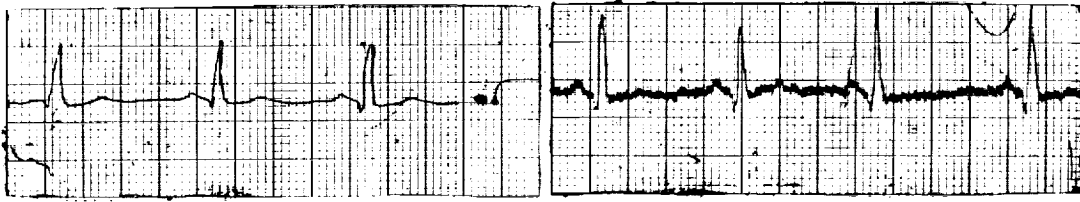
Figure 10.- Irritation caused by bentonite 50 percent CaCl after 38 hours.



Start

End (24 hours)

(a) Stamped cup.



Start

End (24 hours)

(b) $\frac{3}{8}$ -inch stainless-steel mesh.

Start

End (23 hours, 10 min.)

(c) $\frac{1}{2}$ -inch stainless-steel mesh.

Start

End (14 hours, 20 min.)

(d) Fluid electrode.

Figure 13.- Representative ECG with various electrodes.

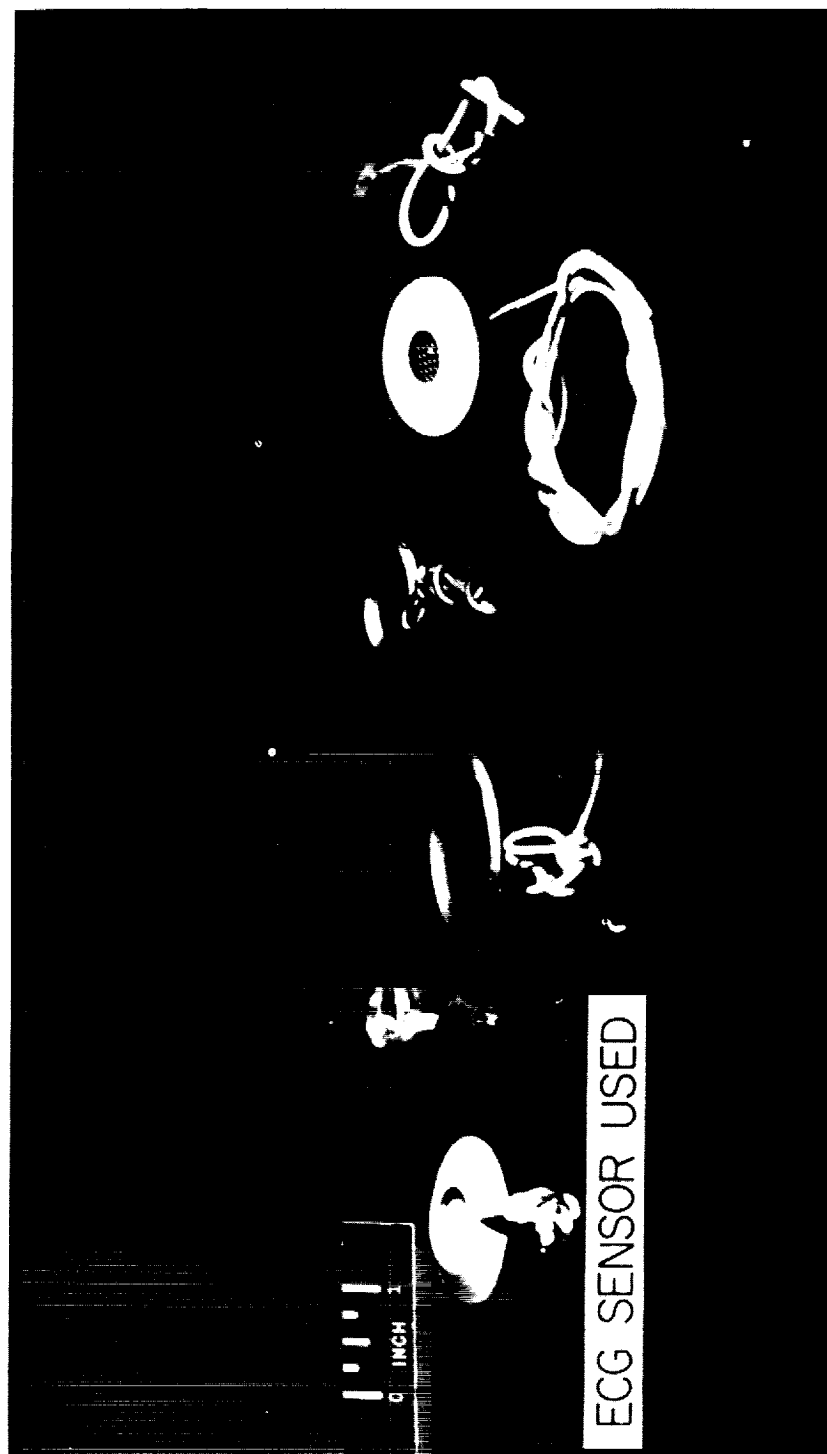
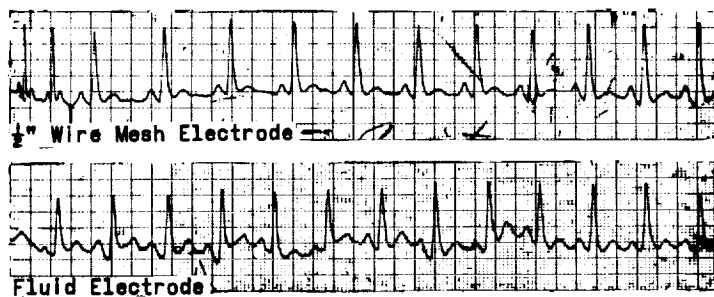
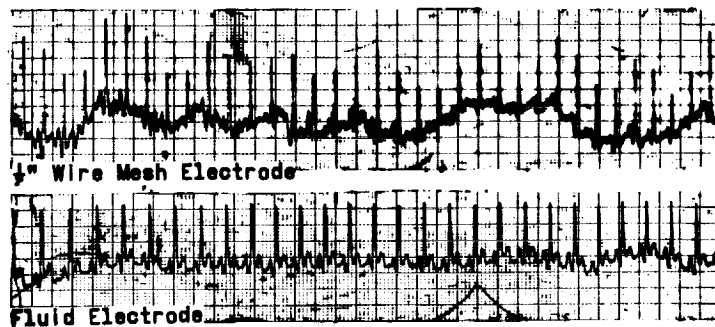


Figure 12.- Various ECG electrodes tested.

S-61-2422



(a) Sitting on table.



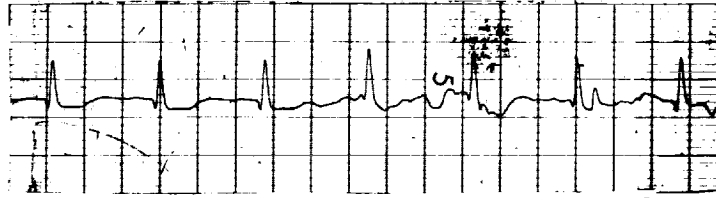
(b) Arms forward.



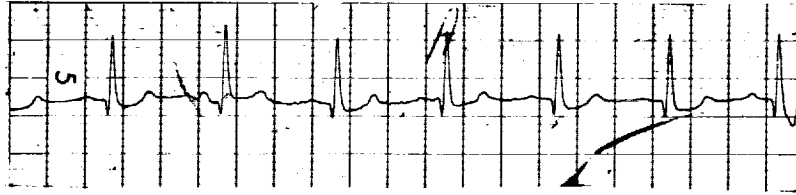
(c) Deep knee bends.

S-61-2427

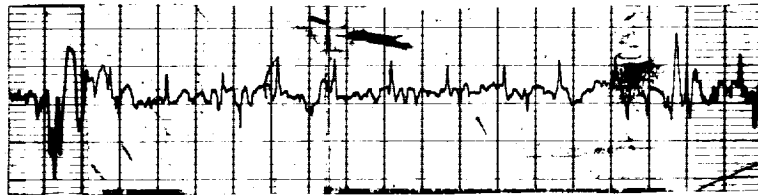
Figure 14.- Comparison of two types of ECG electrodes during various body movements.



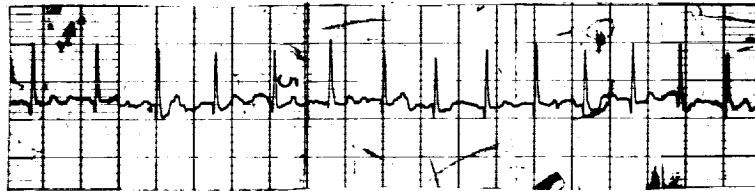
(a) $\frac{1}{2}$ -inch wire mesh electrode attached with vinyl cork. (Static)



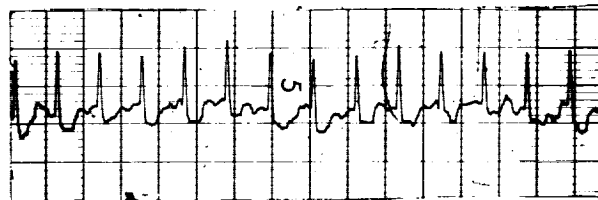
(b) Fluid electrode. (Static)



(c) $\frac{1}{2}$ -inch wire mesh electrode attached with 2-inch square coverlets (4g).



(d) Fluid electrode (4g).



(e) $\frac{3}{4}$ -inch wire-mesh sandwich attached with vinyl cork (4g).

Figure 15.- ECG records during accelerations taken with various electrodes and attachments. All electrodes were placed at the same locations - left and right side on axilla line and left nipple.



Figure 16.- Front view showing placement of ECG electrodes. S-61-2421

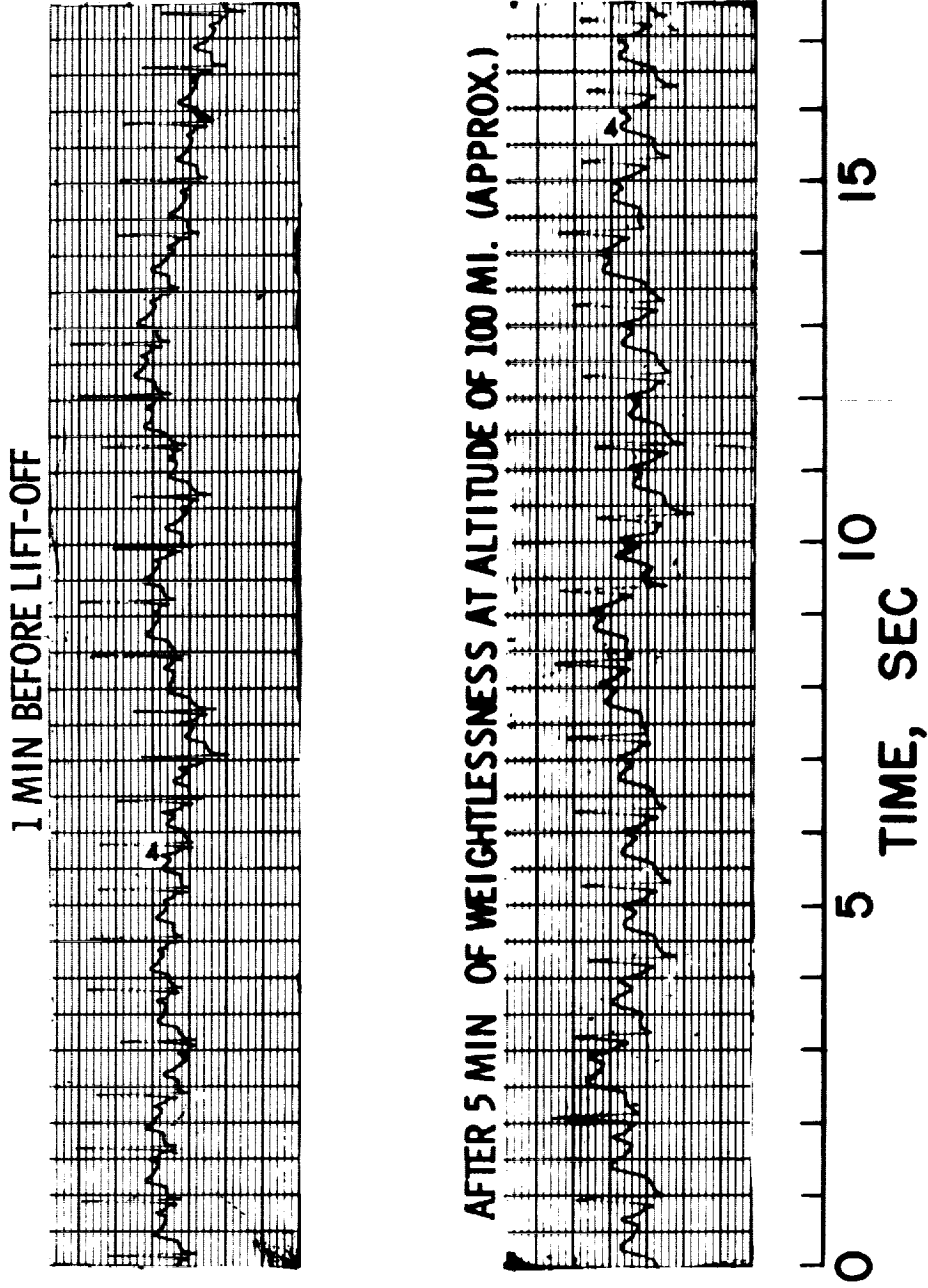


Figure 17.- ECG record from MR-3 flight. S-61-2420



Figure 18.- ECG attachment on chimpanzee. S-61-2419

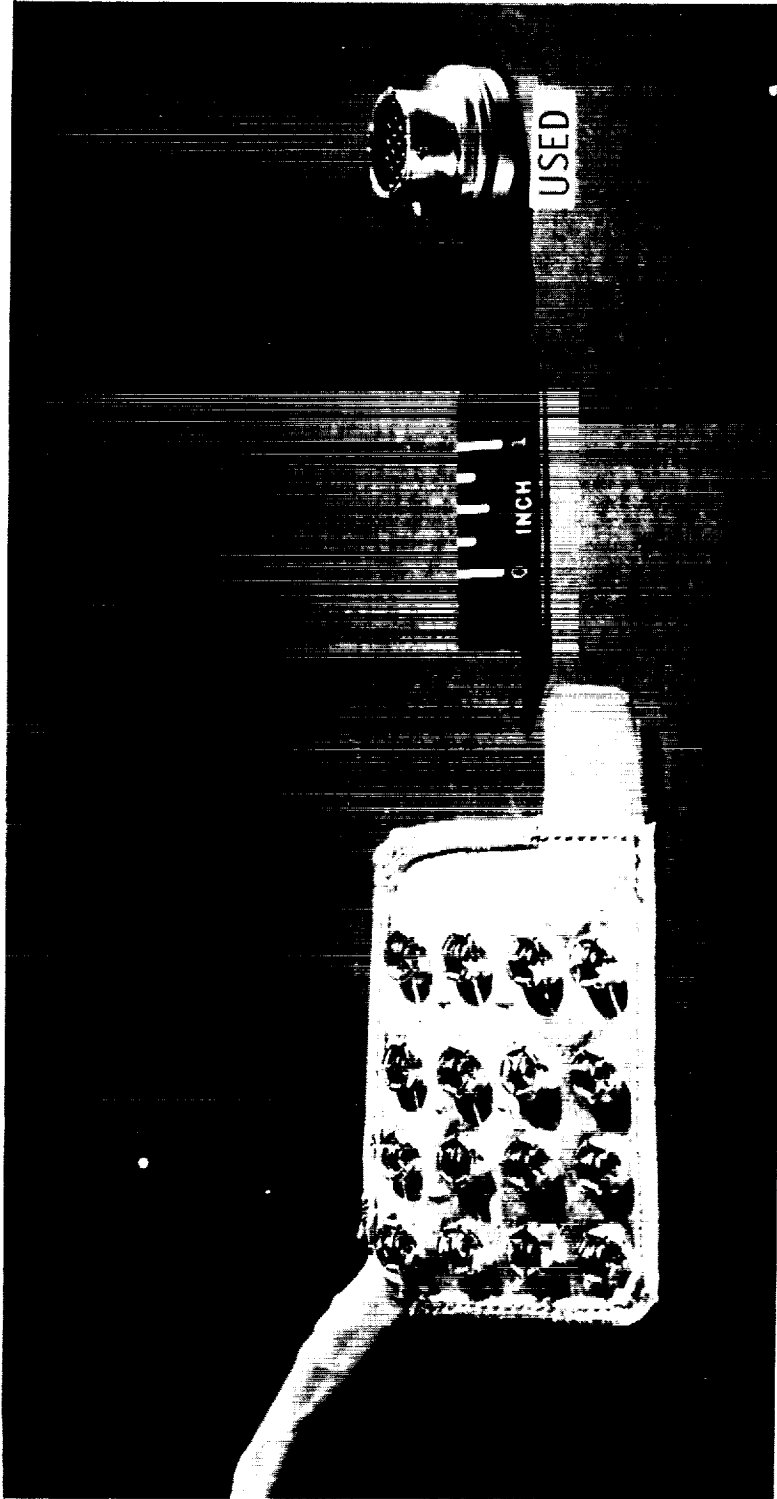


Figure 19.- Two bioconnectors tested.

S-61-1312.1

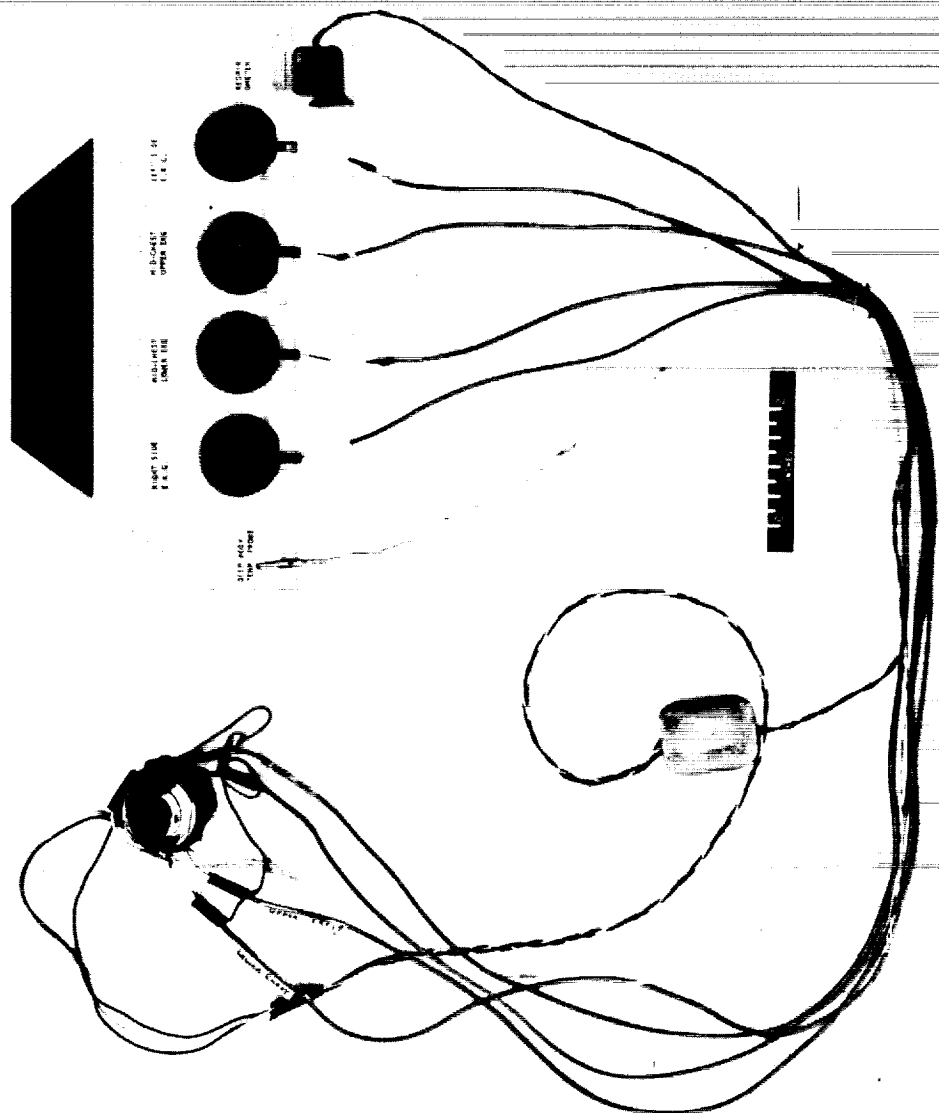


Figure 20.- Biosensor assembly.

<p>NASA TN D-1082 National Aeronautics and Space Administration. PHYSIOLOGICAL SENSORS FOR USE IN PROJECT MERCURY. Charles D. Wheelwright. August 1962. 37p. OTS price, \$1.00. (NASA TECHNICAL NOTE D-1082)</p> <p>Results of tests of biosensors for measuring body core temperature, respiration rate and depth, and electrocardiogram on animals and humans are presented. Comments are made on the bioconnector and biosensor assembly and the possible use of blood-pressure sensors in space flight.</p>	<p>I. Wheelwright, Charles D. II. NASA TN D-1082 (Initial NASA distribution: 8, Behavioral studies; 9, Biomedicine; 11, Biology; 45, Research and development facilities.)</p> <p>NASA</p>
<p>NASA TN D-1082 National Aeronautics and Space Administration. PHYSIOLOGICAL SENSORS FOR USE IN PROJECT MERCURY. Charles D. Wheelwright. August 1962. 37p. OTS price, \$1.00. (NASA TECHNICAL NOTE D-1082)</p> <p>Results of tests of biosensors for measuring body core temperature, respiration rate and depth, and electrocardiogram on animals and humans are presented. Comments are made on the bioconnector and biosensor assembly and the possible use of blood-pressure sensors in space flight.</p>	<p>I. Wheelwright, Charles D. II. NASA TN D-1082 (Initial NASA distribution: 8, Behavioral studies; 9, Biomedicine; 11, Biology; 45, Research and development facilities.)</p> <p>NASA</p>
<p>NASA TN D-1082 National Aeronautics and Space Administration. PHYSIOLOGICAL SENSORS FOR USE IN PROJECT MERCURY. Charles D. Wheelwright. August 1962. 37p. OTS price, \$1.00. (NASA TECHNICAL NOTE D-1082)</p> <p>Results of tests of biosensors for measuring body core temperature, respiration rate and depth, and electrocardiogram on animals and humans are presented. Comments are made on the bioconnector and biosensor assembly and the possible use of blood-pressure sensors in space flight.</p>	<p>I. Wheelwright, Charles D. II. NASA TN D-1082 (Initial NASA distribution: 8, Behavioral studies; 9, Biomedicine; 11, Biology; 45, Research and development facilities.)</p> <p>NASA</p>
<p>NASA TN D-1082 National Aeronautics and Space Administration. PHYSIOLOGICAL SENSORS FOR USE IN PROJECT MERCURY. Charles D. Wheelwright. August 1962. 37p. OTS price, \$1.00. (NASA TECHNICAL NOTE D-1082)</p> <p>Results of tests of biosensors for measuring body core temperature, respiration rate and depth, and electrocardiogram on animals and humans are presented. Comments are made on the bioconnector and biosensor assembly and the possible use of blood-pressure sensors in space flight.</p>	<p>I. Wheelwright, Charles D. II. NASA TN D-1082 (Initial NASA distribution: 8, Behavioral studies; 9, Biomedicine; 11, Biology; 45, Research and development facilities.)</p> <p>NASA</p>

